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# TECHNICAL NOTE

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## RESEARCH PROBLEMS PERTAINING TO AIRCRAFT OPERATIONS

By the NASA Research Advisory Committee on
Aircraft Operating Problems

Edited by
William A. McGowan and William S. Aiken, Jr.

NASA Headquarters
Washington, D.C.



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON March 1963

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# PREFACE

The leadership in commercial transport aircraft design and manufacture that the United States has commanded for the past two decades is now seriously threatened by foreign competition, and there is a real danger in failing to recognize the need for continued adequate research to maintain our technological advantage. To maintain this leadership, we must vigorously and expeditiously conduct basic and applied research programs which will permit the conception of superior aircraft, military as well as commercial.

Our National Defense position demands that superior aircraft be developed for our protection from our enemies. Our economy requires superior aircraft in order to maintain our foreign trade position, if not to maintain the aeronautical prestige that NASA and its predecessor NACA have acquired throughout the years from its judiciously planned and well executed research programs.

Furthermore, we must accept the premise that commercial supersonic flight should not be unnecessarily delayed. It must be considered the next logical development in the progress of air transportation. Unfortunately, there is very little military experience to guide the aircraft designer and the airline engineer in preparing intelligent specifications and requirements for commercial supersonic aircraft operation. Many of the problems involved still require solution; nor is there available sufficient research data to serve as guide lines.

Science has not yet completely answered all questions relating to the sonic boom and to what degree it is tolerable to humans, the behavior and life of structures subjected to elevated temperatures and to comparatively rapid changes in temperature and the effects of radiation at the higher flight altitudes and the protection required. These are but a few of the examples where technological and usable information is still sadly lacking.

Furthermore, to assure dependable operation of aircraft, we must also provide the means to permit scheduled flights irrespective of weather and climatic conditions. All-weather flight is mandatory if air transport is to find its proper place in our National Transportation System.

Aviation is a highly dynamic industry and the advent of high subsonic commercial flying has uncovered new problems which require additional research to enhance flight safety and broaden the usefulness of this mode of transportation. While the importance of aerospace research cannot be denied, we must, nevertheless, have a better appreciation of the research needs required to improve our expanded use of subsonic and supersonic aircraft.

It is with all the above in mind that the Advisory Committee on Operating Problems created an Ad Hoc Committee to list and discuss the research areas needing further investigation, and submit new problems requiring urgent solution.

Charles Froesch
September 10, 1962

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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## SUMMARY

Research problems are presented under the following twelve categories: (I) vehicle performance, (II) vehicle structures, (III) vehicle power plants, (IV) fire hazards, (V) environment, (VI) stability and control, (VII) air traffic control and communication, (VIII) collision avoidance, (IX) instrumentation, (X) medical and human factors, (XI) crashworthiness, and (XII) community relations. Specific recommendations of research studies needed in each of the categories are given first. In appendix A the research problem areas are reviewed and discussed.

## INTRODUCTION

The initial operational phase of large supersonic aircraft and subsonic turbine-powered aircraft has uncovered many problems requiring further research to improve the flight safety, control characteristics, and operating efficiency of these types of aircraft. In addition, military and commercial requirements for a wider range of flight speeds and vehicle types dictate an aggressive research program in order to permit development of advanced design vehicles as V/STOL and supersonic transport aircraft.

This report highlights problems and problem areas and recommends further research studies which the panel feels require satisfactory resolutions to improve the efficiency and safety of operation and permit practical conception of new vehicles. The research projects suggested were based on an overall look at operating problems and, for this reason, do not necessarily fall under the cognizance of any single governmental agency or operators of aircraft; rather, these are general problems which must be solved by the cooperative efforts of all concerned. Further work by specific groups concerned with each problem area is required to delineate how and where or who should do the specific projects. The relative priority of the various areas of research is not established in this report, but the Committee urgently recommends that the research be expedited for the guidance of the military and commercial industry.

Since the time this report was initiated, the problem areas discussed herein have been further defined by industry and Government agencies. In addition, many applicable research contracts have been sponsored by the NASA, FAA, and the USAF, and there is considerable Government and industry in-house effort being made to resolve the more critical problem areas presented.

This report has been prepared by a panel of the NASA Research Advisory Committee on Aircraft Operating Problems. The Chairman of the panel was Mr. Charles Froesch of Eastern Air Lines, and the members included: James Pyle, FAA; Melvin N. Gough, CAB; Warren Dickinson, Douglas Aircraft Company; Otto Kirchner, The Boeing Company; Jerome Lederer, Flight Safety Foundation; R. L. Thoren, Lockheed Aircraft Corporation; R. D. Kelly, United Air Lines; N. A. Lieurance, U.S. Weather Bureau; Irving Pinkel and George Bates, NASA.

## NASA RESEARCH ADVISORY COMMITTEE ON AIRCRAFT OPERATING PROBLEMS

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Mr. George P. Bates, Secretary - NASA Headquarters

## RESEARCH RECOMMENDATIONS

Recommendations are made for research under the following categories of operating problems: (I) vehicle performance, (II) vehicle structures,

(III) vehicle power plants, (IV) fire hazards, (V) environment, (VI) stability and control, (VII) air traffic control and communication, (VIII) collision avoidance, (IX) instrumentation, (X) medical and human factors, (XI) crashworthiness, and (XII) community relations. Certain of the categories cover extensive problem areas and are subdivided into two or more related areas of research. The research recommendations are kept brief so the extent of the required research can be more readily visualized. A review and discussion of the operating problems leading to the research recommendations are given in appendix A.

I. Vehicle Performance

1. Maximum Lift

(a) Develop adequate means of measuring maximum usable lift taking into account dynamic and slipstream effects.

(b) Determine climb performance requirements for some V/STOL and supersonic configurations.

2. Off-Design Performance

(a) Evaluate methods of achieving best overall performance in various off-design configurations including use of automatic optimization of fuel-use parameters.

(b) Substantiate performance methods on flight simulators.

(c) Determine adequacy of existing speed spreads (between design and operational) and inadvertant speed increases for supersonic transports.

(d) Establish quantitative stability and control criteria for supersonic transport aircraft through simulator study.

3. V/STOL Aircraft

(a) Investigate operating problems associated with commercial service.

(b) Expand NASA study concerning temperature and altitude accountability as applied to rotocraft height-velocity diagram.

(c) Facilitate landing area development and aircraft certification with full-scale research on jet impingements, downwash, and recirculation.

(d) Develop practical methods of propulsion interconnect devices for symmetry of lift with partial power failure.

(e) Initiate a program to develop aircraft of greater speeds.

(f) Investigate accident prevention in relation to metropolitan operation.

(g) Develop adequate stability augmentation system.

(h) Develop pilot instruments for visual indication of actual flight path for steep-gradient operation.

(i) Develop accurate airspeed indicator for low speed flight in all directions.

(j) Make analysis of energy expenditure per ton mile of translation for comparison with other modes of transportation.

4. Safety Requirements

(a) Establish operational safety requirements.

5. Fuel Reserves

(a) Establish, in cooperation with the NASA, FAA, airlines, and manufacturers, the fuel reserve requirements of the supersonic transport in light of progress and stricter operating procedures.

6. Performance Potential

(a) Define the optimum utilization of the supersonic transport at speeds within the performance potential.

7. Aircraft Noise and Sonic Boom

(a) Investigate design of fan air inlets and compression stages and their relation to inlet noise.

(b) Coordinate noise abatement research and operational practices and actual performance margins.

(c) Determine special performance criteria required by noise problems generated by climb-out and the sonic boom.

8. V/STOL Noise

(a) Define the maximum and minimum performance of V/STOL aircraft during take-off/climb and approach/descent to show comparative noise level.

II. <u>Vehicle Structures</u>

1. Environmental Factors

(a) Determine applicable loads data related to air turbulence at all altitudes.

(b) Study the effect of high frequency vibrations on structural life and determine basic structural configuration for maximum resistance.

(c) Make statistical study of gust loads, temperature, fuel sloshing, transient loads, heat stresses for all types of high subsonic and supersonic transports and bomber type aircraft.

(d) Determine radiation characteristics of the atmosphere and effects on personnel and materials.

2. Primary Structure Composition

(a) Enunciate design parameters for structures subjected to high pressurization loads, temperature, and pressure changes and low heat and high heat input for extended periods.

(b) Develop structural designs with good heat dissipation coupled with maintenance and inspection ease.

(c) Recommend integral fuel tank design to minimize corrosion cause by micro-organisms with petroleum base fuels and withstand wide and rapid changes in temperature and pressure.

(d) Review the fatigue problem and recommend basic fail-safe design criteria.

III. Vehicle Power Plants

1. Flame-Out

(a) Develop a flame-out sensor and rapid combustor relighter.

(b) Determine effect of rain, hail, and ice crystals on engine and air inlet configurations.

(c) Evaluate flame-out tendencies due to turbulence and maneuvering transient conditions at high altitude and speeds to Mach 3.

2. Engine Response Simulation

(a) Devise computer equipment to simulate response of turbine engine-propeller-fan power plant.

(b) Study likelihood of single and multiple failures occurring in a complex engine control system.

(c) Evaluate consequences of possible failures in the engine control system.

(d) Determine the critical aspects of interrelated control systems in supersonic transport propulsion systems, including inlet and exhaust variable geometry controls.

3. Supersonic Transport Engine Inlets and Nozzles

(a) Develop means for rapid adjustment of the variable engine inlet and exhaust nozzle as related to the flight Mach number requirements.

(b) Derive safety objectives for engine inlet and nozzle operation throughout the design envelope to insure that no single failure or likely combination of malfunction will produce an unsafe condition.

4. Foreign Object Ingestion

(a) Develop foreign object inlet deflectors and traps as part of the engine installation design.

5. Fuels, Lubricants, and Hydraulic Fluids

(a) Improve high temperature stability of fuels, lubricants, and fluids.

## IV. Fire Hazards

(a) Search for tank sealants which avoid dangerous electrostatic generation.

(b) Study mechanics of ignition by electrostatic sparks.

(c) Evaluate the effects of the following on surface ignition:

fuel and surface temperature
surface roughness and orientation
fuel-air ratio
pressure altitude
Reynolds and Prandtl number ventilation airflow over surface

(d) Explore methods of inerting fuel vapor and provide indication to crew

## V. Environment

1. Clear Air Turbulence

(a) Establish the meteorological mechanism producing clear air turbulence.

(b) Develop techniques for precisely identifying areas of clear air turbulence in time and space and for forecasting its existence and intensity.

2. Severe Storms

(a) Refine the definition of the intensity and characteristics of turbulence, hail, and electrical charges.

(b) Determine the mechanism of severe storms and refine the means of identification and forecasting the movement, intensification, and decay.

3. Pilot Visibility Requirement

(a) Develop a system to measure and report the pilots' cockpit visibility during final approach and develop techniques for forecasting this visibility up to 2 hours in advance.

(b) Investigate techniques to improve visibility in the terminal areas, i.e., artificial fog dissipation.

4. Upper Air

(a) Refine the system to routinely and accurately measure the upper air winds, pressure, and temperature to 100,000 feet and determine the cause of significant changes that occur at standard levels during 6, 12, and 24 hour intervals.

(b) Establish the ozone and cosmic radiation levels that exist to altitudes of 100,000 feet.

(c) Publication of the complete climatology of the upper air to 100,000 feet on a global basis is required for design, manufacture, and operational planning. These studies should include the temperature, humidity, winds, and pressure; their means, extremes, and variability together with the statistics of clouds, turbulence, ozone, and cosmic radiation.

(d) Develop warning methods for cosmic radiation and ozone levels, if necessary, so flights can be diverted.

5. Operational Meteorological Requirements

(a) Assess the relative significance of weather parameters in the terminal and en route areas.

VI. Stability and Control

1. Operational

(a) Compare flying and handling qualitites of present jets and turbo-props against current military specifications to determine minimum requirements for safety.

(b) Determine commercial user's control and stability problems on current transports and establish means to evaluate and alleviate them.

(c) Define handling quality specifications for present commercial aircraft from a piloting aspect.

(d) Develop suitable blind landing systems.

(e) Study landing aids and instrument flight problems and requirements including information presentation to the pilot.

(f) Establish stability and control requirement under VFR and IFR flight conditions for V/STOL and supersonic aircraft.

(g) Improve control and handling procedures of vehicles on the ground.

2. Stall Characteristics

(a) Determine effect of angle-of-attack limitation of highly swept wings on operating procedures and safety requirements during landing and take-off.

3. Dynamic Stability Requirements

(a) Establish a criterion for longitudinal and lateral directional dynamic stability (especially in Dutch roll coupling) for supersonic commercial aircraft.

4. Simulation Studies

(a) Simulate approach and landing, with adequate vertical motion, of a supersonic transport type aircraft.

5. Trim Capabilities

(a) Review the present concepts of primary and secondary control systems to bring to light system failures that could take complete charge of the airplane.

VII. Air Traffic Control and Communications

(a) Establish requirements on the precision of flight.

(b) Determine compatibility of various aircraft classes with control requirements.

(c) Study the mutual impact of aircraft characteristics and traffic control demands on the overall safety of the transport system.

(d) Establish the environmental effects on air traffic control and the requirements for essential meteorological services.

VIII. <u>Collision Avoidance</u>

(a) Develop a suitable design of a Collision Avoidance System.

(b) Improve airborne altimetry systems for use in a Pilot Warning Instrument.

(c) It is recommended that:

all programs be coordinated with the FAA Collision Prevention Advisory Group

maximum attention be placed on the development of CAS systems

an inexpensive Pilot's Warning Instrument be developed for private aircraft

a dual method be set up for collision avoidance.

IX. <u>Instrumentation</u>

(a) Develop improved methods of measuring:

Altitude
Temperature
- ram
- static
- structure
- engine
- fuel

Fuel quantity
Thrust
Fuel vapor inerting indicator
Stall speed
Attitude

X. <u>Medical and Human Factors</u>

1. Cabin Noise

(a) Develop new and more efficient sound attenuation techniques for passenger comfort.

(b) Further research in boundary-layer noise.

2. External Vision

(a) Study experience of general and sea transportation systems to determine acceptance of external vision desirability.

3. Medical Qualification

(a) Tests delineating human performance in the dynamic situations (flying tasks and associated phenomena) to be expected should be developed and applied.

(b) Investigate the requirements and recommend physiologic training for the crews.

(c) Investigate problems associated with stresses of operation, biological time belt change, and work loads in flight and their relation to the determination of a true aging factor for the pilot and crew.

4. Rates of Descent

(a) Ascertain desirable and acceptable procedures for descents in emergency.

(b) Determine the minimum safe altitude pressure to which passenger and crew can be transiently exposed.

5. Passenger Indoctrination

(a) Devise a means of predicting passenger response to critical in-flight emergencies to provide automatic protection or determine essential indoctrination procedures which may be used.

6. Radiation

(a) The effects of cosmic, solar, and fall-out radiation on crew and passengers of vehicles operating up to altitudes of 100,000 feet must be determined.

(b) Keep current a summary statement on radiation phenomena effects on crew and passengers of high altitude vehicles.

7. Ozone

(a) Define the problem areas associated with passengers and equipment.

XI. <u>Crashworthiness</u>

(a) Continue studies of the physiological capacity of the human body to withstand "G" forces, with various types of restraint.

(b) Develop the principles of occupant seat design to establish safe forward, sideways, and rearward facing seats.

(c) Study the collapse or deformation and energy absorbing characteristics of structures.

(d) Establish delethalization design principles for seats, cabins, and cockpits.

(e) Establish design principles for structure and fuselage contents so as not to impede personnel escape during emergency evacuation.

(f) Develop improved emergency inside and outside lighting and communication systems.

(g) Establish escape route principles.

(h) Establish instinctive design requirements for operating emergency equipment - latches, handles, exits, etc.

(i) Establish design requirements for jam-proof emergency doors, etc.

(j) Continue studies that will lead to use of less flammable fluids.

(k) Establish appropriate types of survivable crashes for each type of aircraft to facilitate designing for crash survival and escape.

(l) Explore means of reducing the energy of an impending airplane crash from the standpoint of preventing injuries and aiding escape.

XII. Community Relations

1. Technical

(a) Further research to reduce basic sources of noise.

(b) Plan airports and safe flight patterns to reduce the noise and smoke nuisance.

(c) Improve aircraft take-off run and rate of climb.

(d) Provide for crash fire suppression and train and equip local fire departments to attack aircraft fires.

(e) Establish tolerance limits for sonic booms and determine factors affecting strength of the booms.

2. Sociological

(a) Prove to the public the advantages of aircraft and the steps being taken to reduce the noise and hazards.

(b) Determine flight restrictions imposed by nations and communities especially concerning the sonic boom.

National Aeronautics and Space Administration,
Washington, D.C., Sept. 10, 1962.

## APPENDIX A

## DISCUSSION

As previously pointed out, the research recommendations have been briefly stated to enable the reader to visualize the extent of the studies required to (1) improve present aircraft operations and (2) permit development of advanced design aircraft. In this section the present state of the art and problems anticipated with the supersonic transport and V/STOL aircraft from which the aforementioned research recommendations were formulated will be discussed. Insofar as practical the discussion will be presented using the same format as in the Research Recommendations section.

### I. Vehicle Performance

#### 1. Maximum Lift

Definite limits are placed on various areas of aircraft performance by the controlled maximum lift which may be generated. The present methods used to measure "stall speed" do not provide an accurate measure of maximum usable lift. Accurate measurements are difficult because maximum load factors accompanying minimum speeds vary widely from aircraft to aircraft, as do rotational velocities at lift-off. In addition, control problems often dominate operational techniques. Adequate flight research has already been accomplished to enable accurate measurement of stall speed for a delta wing configuration. However, maximum usable lift for a low aspect ratio configuration, such as might be used on a supersonic transport, is currently defined by an arbitrary angle-of-attack cut-off.

The effect of slipstream on the maximum lift is not accurately accounted for in current regulations and dynamic effects on maximum lift are not adequately covered by experimental data. NASA work related to the slipstream effect on maximum lift has already begun and some previous NACA work was done on the dynamic effects on maximum lift on very small scale models and on World War II fighter types. These programs do not provide adequate information upon which to predict maximum lift available in gusts or while maneuvering at higher Reynolds numbers or Mach numbers and with thin airfoils. This NASA work should be extended to cover all conventional types of aircraft as well as V/STOL types and should be also extended into the high-speed maneuver area as well as for take-off conditions.

Realizable climb performance requirements to provide minimum safe flight paths for V/STOL and supersonic transport configuration should be investigated. Current concepts of take-off and climb gradients are based on past and present flight equipment. Future vehicles will probably have different power-required curves and configurations that will place different demands on the precision of flight to obtain book performance.

A flight research program covering the above problem areas would enable government agencies to utilize the data obtained to create consistent and adequate regulatory material and enable industry to accomplish a knowledgeable design and performance analysis.

2. Off-Design Performance

The planned increase in the area of the speed-altitude envelope of future aircraft implies an increase in performance and compromises to accommodate loss of engine power, extreme weather conditions, traffic control problems, etc. The use of automatic optimization of fuel-use parameters under all flight conditions may be desirable and would be particularly important under off-design conditions. Parameters affecting power-plant performance could be introduced automatically from basic air data and fuel and engine sensors to give optimum Mach number, altitude, and range conditions.

3. V/STOL Aircraft

The NASA is at present doing considerable work on V/STOL airplane configurations and this work should be expanded to solve problems anticipated upon introduction of such airplanes into commercial service.

In most flight modes, particularly when utilizing vertical and near vertical flight paths and in hovering, most V/STOL aircraft require stability augmentation systems. The degree of system sophistication depends upon the design and flight conditions, with instrument flight requiring the highest order of refinement. The primary handling quality design goal is to ensure adequate control augmentation about all axes.

4. Safety Requirements

The present FAA Civil Airworthiness Manual 7 covering Rotorcraft-Transport Category would be inadequate if applied to a heavy V/STOL airplane of say, 200,000 pounds. In addition, work of a preliminary nature to investigate the applications of necessary safety requirements on V/STOL aircraft could be used to determine the attendant operational penalties.

5. Fuel Reserves

New regulatory fuel reserve standards for the supersonic transport should be developed considering improved communications, navigation systems, air traffic control, all-weather landing systems, and airports. These improvements may make alternate airports unnecessary and diversionary airports en route may suffice for continental operations and result in reduced amount of reserve fuel. Points of destination without diversionary airports en route could require an additional fuel reserve for possible engine failure, error in flight planning, weather, and other operational variables. The fuel reserve for this type of operation could be predicted for the individual route.

The airlines should be able to provide a valuable input in establishing proper fuel reserves. The fuel reserve of the supersonic transport is a serious problem as it has a large influence on aircraft size and operating economics.

V/STOL aircraft are capable of carrying out many different mission profiles which dictate different payloads and fuel requirements; i.e., short take-off with vertical landing at destination, conventional take-off with either short or vertical landing at destination. The establishment of fuel reserve requirements must not unnecessarily restrict the mission capability of the V/STOL aircraft.

6. Performance Potential

Considerable emphasis has been given to the relative advantages of the Mach 3 transport of stainless steel or titanium construction and the Mach 2 transport of aluminum construction. One expressed advantage of the Mach 3 aircraft is the performance potential in the Mach 4 to 5 range. At these Mach numbers important changes in operational characteristics will become necessary as the use of curvilinear flight paths becomes a measurable factor. Only small increases in block speed result from large increases in cruise speed unless substantial changes in range profile are made.

7. Aircraft Noise and Sonic Boom

The effects of aircraft noise on the community are becoming severe and the noise generated by the supersonic transport will be an important factor affecting operational performance. Restriction of aircraft operation from the optimum or design manner would probably be an unacceptable load for a supersonic transport.

Sonic boom pressures will be generated during supersonic flight and, while work has been done and is being continued with fighter and bomber airplane types, extensive research in all facets of the sonic boom phenomenon is required to alleviate the problem associated with commercial supersonic transport operation.

8. V/STOL Noise

A partial solution to some community noise problems might be found in the use of V/STOL aircraft with their highly localized sound source at take-off and landing. However, use of V/STOL aircraft within towns may increase noise problems because of the extremely high thrust levels required of the operation. Although steep approach and departure profiles will help in some cases there is a need for full-scale testing to determine all possible methods of reducing radiated noise.

## II. Vehicle Structures

The following discussion is intended to emphasize the importance of required structures research outlined and defined in NASA Technical Note D-518 entitled "Important Research Problems in Advanced Flight Structures Design," 1960. Research is required to (a) determine the effects of environment on structures within and beyond the earth's atmosphere and (b) determine the primary structural compositions required to meet the rapid and wide environment and load changes.

1. Environmental Factors

The high speeds of present-day aircraft and the use of supersonic transports and perhaps vehicles capable of hypersonic speeds in the comparatively near future require a reorientation of aircraft structures conceptions to take advantage of new materials and fabricating techniques. Our knowledge of the magnitude and frequency of the application of loads in flight and the fatigue effects of boundary-layer noise on the aircraft structure is still limited.

2. Primary Structure Composition

In general there is a need for structural designs and materials of the best strength/weight ratio that can withstand (a) large pressure changes with minimum deformation, (b) a wide range of corrosive environments due to fuel and temperature, and (c) vibration. Consideration should be given to the design provisions set forth in Navy specification SD-24 to improve airworthiness requirements.

## III. Vehicle Power Plants

In addition to the research needed to improve power-plant efficiency and engine types, problems exist with current engines such as sensitiveness to ingestion of foreign objects, rain, hail, etc. Supersonic transports pose new problems on engine inlets, nozzles, fuels, lubricants, and hydraulic fluids; however, the research and development program needed for these particular problems is not covered herein.

1. Flame-Out

Most turbojets have considerable tolerance to the ingestion, at moderate altitudes, of large amounts of water in its several forms. However, above 40,000 feet compressor stall margins decline rapidly and increase the sensitivity of the engine to ingested water. Likewise, lower combustion chamber pressure at altitude are detrimental to good combustor performance. Pressure perturbations accompanying sudden water ingestion and the pressure of large amounts of water in the combustion air can cause flame-out. Engine inlet icing and momentary yawed flight produced by heavy turbulence or engine failure can distort the inlet air flow and aggravate the flame-out problem. Such inlet icing can occur at high altitude since the engine can no longer divert the necessary mass flow of air from the compressor to heat the inlet to prevent ice accumulation. Heavy icing conditions and high turbulence have been reported in the tops of high cumulus clouds. When avoidance of cumulus clouds is not possible penetration is usually done at reduced engine speed for structural reasons, but also makes flame-out more likely. Engine ingestion of fuel spilled from wing tanks in flight becomes possible with fuselage and tail mounted engines. Flame-out sometimes accompanies the combustor pressure surge associated with fuel ingestion.

Consideration should be given to the development of a basic engine design that would not have the characteristic flame-out tendencies and low compressor characteristic flame-out tendencies and low compressor stall margins above 40,000 feet altitude of present engines. However, since making major modifications to current engines to alleviate these flame-out problems are unlikely, it is recommended that other means be developed. The most direct approach would be to devise an ignitor which senses flame-out for the combustor and comes on at once. Rapid action is desired so ignition occurs while the combustor pressure is still high enough to permit relight. If the engine rotational speed declines appreciably following flame-out it may be necessary for the airplane to descend to lower altitude to effect a relight.

The need for flame-out detectors can be avoided if a suitable continuous ignition system is provided for use during take-off and flight in bad weather. A parallel program to investigate glow-plugs for relighting the combustor is also desirable and promising developments already exist. Required now is an evaluation facility for determining the limits of combustor operation pressure and temperature at which consistent relights by the glow-plug occur. These limits then would establish the flight altitudes over which the glow-plug is effective. The most effective location of the glow-plug in the combustor is an item for study as well.

Ignitor and glow-plug developments are handled best by the manufacturers of this equipment. Evaluation facilities may have to be furnished by the aviation industry or government and should be capable of permitting the evaluation of the performance of ignitors and glow-plugs in combustors taken from any engine. Airflow through the combustor should simulate flight conditions from sea level to 80,000 feet.

2. Engine-Response Simulation

Actuation of cockpit engine controls in an emergency sometimes stimulates the automatic turbine engine and propeller controls to engage in an operation of these parts which heightens the emergency. The circumstances under which this development may happen are sometimes revealed in the course of an accident inquiry. It would be advantageous if such circumstances could be studied in detail before automatic control and cockpit procedures are fixed. The FAA requires a fault analysis study of each engine control system under a variety of different conditions, many of which are imposed during actual operational testing in the course of development and certification programs. New control concepts are usually analyzed by means of analogs, or other equivalent techniques, during the manufacturer's development program. However, as more complex controls are introduced, such as on the supersonic transport, computer studies will be necessary to secure knowledge of the behavior of the engine under many forms of departure from normal functioning, including plausible multiple failures.

A joint FAA-NASA-Industry ad hoc team should specify the capability of the analog and digital computers used. If current computers meet the specifications a review should be made of their use and distribution of information obtained.

3. Supersonic Transport Engine Inlets and Nozzles

Although considerable work on inlets and nozzles for Mach 2 to 3 flight has already been done special problems in design will arise with the specific airplane configuration and flight program chosen and will require additional study. Items of inlet and exhaust nozzle design which require studies of fundamentals should be supported by NASA-FAA. Problems in actuation and control of variable geometry inlets and exhaust nozzles should be resolved by the airplane manufacturer. Work should begin as soon as a decision is made regarding the airplane configuration.

The flow control of the engine inlet and exhaust nozzle is related to the flight Mach number and the volume flow of air and requires rapid adjustment with emergency change in engine airflow. The method of attaining necessary safety objectives are far from clear and research work should be directed toward this end. There is need for work in at least two primary phases in an installation of this sort: first, to assure that the system will enable the airplane to be operated in a safe manner throughout its design envelope; and second, to ensure that no single failure or likely combination of failures involving the inlet and exhaust systems will produce an unsafe condition.

4. Foreign Object Ingestion

The seriousness of ingestion of foreign material depends largely on the amount and type of material involved. Ingestion of foreign material has caused fatal accidents.

Safety screens over the engine inlet have the disadvantage of possible clogging by debris and ice and impose a thrust penalty by impeding the engine inlet flow. To avoid some of the penalities of safety screens inertia separation techniques should be explored. These techniques fall into two main classes. One class has the form of a streamlined body set forward of the engine inlet which deflects solid objects out of the main engine airflow. A second class takes advantage of bends in engine inlet ducting which traps or bypasses the foreign object. Efforts should be continued to find new or better ways to reduce foreign object damage.

Inlet designs with "smooth bore" interiors would reduce the possibility of foreign object damage due to fractured bits and parts, such as fasteners in the inlet interior. Studies of different make engine compressor and turbine blade strength could be made to determine the design best suited to withstand debris ingestion.

5. Fuels, Lubricants, and Hydraulic Fluid

Aerodynamic heating experienced by a Mach 3 transport may raise the temperature of fuels contained in the tanks above 250° F. Also the fuel may be used as a heat sink, as it flows to the engine, and provide a cooling capacity for vital airplane zones. This fuel may attain temperatures to 500° F for a short time. A study is needed now to determine whether fuels of high thermal stability are economically available in quantities required for commercial transport use. Equally critical is the development of lubricants and hydraulic fluids for high temperature service. Consideration should be given to development work in support of the B-70 program.

Other problems with fuels are related to the growth of fungus in integral fuel tanks and transparent films or slimes that accumulate on filters.

## IV. Fire Hazards

The effect of elevated temperature on stored combustible liquids and the mechanics of fuel ignition on hot surfaces should be studied. There is a need for a practical crash fire inerting system for transport operations and to determine whether there is a safety hazard introduced as a result of electrostatic generation.

Storage of combustible liquids at elevated temperatures increases the ease of ignition. The supersonic transport may have a vulnerability to fire which is far greater than is the case for present aircraft using kerosene-type fuels because of the combustible tank atmosphere for an appreciable portion of the flight. Information is required on the mechanics of fuel ignition on hot surfaces in contact with a ventilating airstream in order that rules can be devised for safe ventilating rates. Methods for inerting fuel vapors or excluding air from potential fire zones on the supersonic transport should also be explored.

## V. Environment

Prior to the introduction into service of new aircraft, many years of study, design, and test are necessary. This preparation includes not only the engineering related to the aircraft itself, but also studies related to the supporting services; i.e., navigational aids, passenger and cargo handling facilities, airport design, meteorological, and other essential housekeeping type facilities. During the progressive steps from the single- to the multi-reciprocal engine aircraft to the present class of turbojets, many operating problems were highlighted prior to the introduction into service of each class. In each instance the meteorological problems in general have been almost identical. As progress is made in structures and power plants, navigational aids, and airport handling facilities, some of the meteorological problems have become less important and others more critical. Each incremental increase in speed, altitude, and range introduces a need for the refinement of an existing meteorological service to cope with an old problem rather than creating a new meteorological operational problem.

In reviewing the meteorological deficiencies in support of aviation, it was found that they may be categorized as either scientific or economic. The elimination of the scientific deficiencies requires a research effort; those falling in the economic category, if of sufficient importance, can be solved through the mechanism of budget, organization, management, and application. Since this document is directed toward those areas where there is a scientific deficiency, the following problem areas have a high priority and degree of urgency for solution to enhance the safety of flight.

### 1. Clear Air Turbulence

The occurrence of clear air turbulence at flight altitudes affects present aircraft operations and will become more important as cruising speed increases. This type of turbulence is particularly difficult to cope with because of a lack of adequate means to predict its location.

2. Severe Storms

Tornadoes, thunderstorms, and line squalls produce areas of severe turbulence in the atmosphere and present serious problems for aircraft operation below 50,000 feet. Climatological information on frequency of occurrence, vertical and horizontal extent, and intensity for various parts of the world can be used in aircraft design, operational planning, and the assessment of flight aids and techniques.

3. Pilot Visibility Requirement

As long as the pilot must rely on a visual reference to complete a landing, the measurement and forecasting of values representative of how far and what can be seen from the cockpit during the landing approach is essential. A lack of visual reference during the approach is one of the major factors in aircraft accidents, particularly in general aviation.

4. Upper Air

Wind speed, direction, and temperature and their changes with time are essential for economic long-haul jet operation. There is a lack of detailed information on winds and temperatures between 50,000 and 100,000 feet altitude, particularly over the ocean areas.

Radiation appears to be another major problem both as to its extent and significance. Major research programs are now underway in physical and biological sciences on radiation environments and its effects. Cosmic radiation, especially proton events caused by solar flares, are expected to pose operational problems for high altitude aircraft.

5. Operational Meteorological Requirements

One of the major problems deterring improved meteorology for aircraft operations is the lack of well-defined requirements. The variation of wind, temperature, cloud height, visibility, and precipitation in the terminal area make it difficult with present measurements, if not impossible, to present accurate values for use of the pilot under particular flight conditions. For this reason the meteorological measurements are samples of conditions and are reported as means or averages over a specified interval of time. With the supersonic transport still in the planning stage, a comprehensive and organized study made now to determine the precise terminal weather requirements will assure adequate forecasting when the supersonic transport becomes operational.

## VI. Stability and Control

1. Operational

In considering the operational stability and control problems likely to arise in a potential supersonic aircraft some assumptions are necessary. It will be assumed that such problems as beset present supersonic aircraft as pitch-up, tuck-under, roll coupling, control problems at low speed, etc., are being given all the attention they require in wind-tunnel tests, theoretical analysis, and design proceedings. Other problems will arise in operational use in those fields where compromise has been necessary to secure adequate all-around performance.

2. Stall Characteristics

A supersonic transport with highly swept wing will have a landing and take-off speed limited by a geometric allowable angle of attack rather than by maximum lift coefficient. Present transport take-off and landing requirements are based on an interpretation of maximum lift coefficient from stall speeds obtained in flight. It is likely that actual stall speeds cannot or should not be demonstrated in flight due to the very high angles of attack involved.

If a supersonic transport is developed with variable wing sweep it can be expected to have problems peculiar to the particular design decided upon.

3. Dynamic Stability Requirements

Present military specifications have stringent dynamic stability requirements while the commercial requirements are not as specific. It is recommended that the NASA evaluate aerodynamic and inertia characteristics typical of supersonic transport configurations on their variable stability aircraft to see if current criteria are applicable. Special emphasis is needed in the lateral-directional characteristics where the increase in flight envelope tends to give disconcerting increases in Dutch roll coupling.

4. Simulation Studies

High pitch rates, large vertical translations, etc., will make the approach and landing of a supersonic transport more difficult than current operational aircraft. Work is at present underway at the NASA with a flight simulator with large vertical translational capabilities for VTOL studies. This simulator should also be used for supersonic transport studies.

5. Trim Capabilities

No requirements are in effect for commercial aircraft covering the possible overriding of primary control systems by secondary trim systems. The supersonic transport will introduce many problems in obtaining adequate handling characteristics over the complete speed range and care is needed to prevent secondary system failures causing uncontrollable motions of the airplane.

## VII. Air Traffic Control and Communications

There are many complex problems in this area for which solutions must be found and it is difficult to recommend specific projects which might be undertaken to assist with this task. It is important that FAA and NASA maintain an excellent working relationship whereby assistance in solving specific problems is requested and provided on an entirely informal basis by each agency. Primary emphasis is now being placed on the automation of the nondecision-making functions of the air traffic data for analysis by the controller. The purpose is to relieve the controller of the burden of numerous secondary duties such as manual posting of data, relaying information, coordination with other controllers, etc., which seriously interfere with the primary function of analyzing air traffic situations and making control decisions.

It is also important to integrate Air Traffic Control and the Air Defense Systems to realize the maximum utilization of air defense radar and other aircraft-position-determining information. Special emphasis should be placed on high altitude control and flexibility in the automatic data processing and display system to handle direct (off-airway) flights.

To reduce the congestion in the radio communication channels, the present FAA program includes the development of a three-dimensional radar to provide precise information on aircraft altitude as well as geographical location. Other attacks on this problem are through further development of the air traffic control radar beacon system and direction-finding equipment with emphasis on VHF Doppler DF. The severity of radio voice communications congestion is such, however, that these methods are not sufficient. Further relief is being sought by the development of an automatic air-ground-air communications system designed to provide high-speed exchange of traffic control information between the pilot and controller. This system will also operate in conjunction with the automatic data processing and display system.

The heavy economic burden placed upon the air carriers and other users of the air space due to the inability to land at the designated destination because of adverse weather is the reason for another major effort directed toward the development of an all-weather landing capability. Several approaches to this objective are being pursued so that an effective system can be implemented.

The speed of the aircraft involved in transoceanic traffic is increasing and necessitates improved air traffic control and navigation accuracy. One interim step is the evaluation of the Loran "C" and Dectra Navigation Systems being undertaken in cooperation with the United Kingdom. While another interim approach is the investigation of ocean-station VOR/DME facilities for transoceanic navigation.

Long distance air traffic control cannot be improved without improvements in long distance communications and so this area is receiving attention to take advantage of the most recent advances in the state of the art. Improvement of short distance navigation aids must also be continued together with the development of improved cockpit displays and helicopter navigation.

Although considered as separate subjects in this report, instrumentation and meteorology play important parts in air traffic control. The errors inherent in the barometric altimeter systems installed in current aircraft are recognized as a limiting factor in the capacity of the air traffic control system and a flight safety factor in aircraft operations. The efficiency and effectiveness with which the Air Traffic Control System operates are, in part, weather dependent. Similarly, weather influences the safety and effectiveness of flying. A program to exploit the existing technology in meteorology is being conducted jointly by the Departments of Defense and Commerce.

The FAA with the cooperation of other agencies should evolve requirements and some solutions to the traffic control and communications problems through the simulator set up at NAFEC.

## VIII. Collision Avoidance

### 1. General

It is recognized that positive ground-based air traffic control probably is the optimum method of minimizing air collision while maintaining efficiency of traffic movement. However, economic and technical considerations may limit the possibility of full implementation of such a ground complex for all air space at all times. Accordingly, a program designed to investigate, develop, test and evaluate airborne collision avoidance means must be supported until either a feasible airborne system is developed, or until it is proven that a feasible airborne system cannot be developed. The possibility exists that fully developed airborne devices can operate to provide backup for the common control system and provide adequate protection in areas not serviced by the ground-sited Air Traffic Control complex.

To assist FAA in the development of Collision Avoidance Systems and Pilot Warning Indicators, a Collision Prevention Advisory Group (COPAG) was formed. The group represents the users of the air space and organizations having facilities and competency in this field. The group assists the FAA in considering the requirements of the airspace users, in analyzing and evaluating proposed technical approaches, in performing tests and measurements, and in actual development or supply of hardware.

In the airborne collision prevention program there are three methods being considered (1) Collision Avoidance System (CAS), (2) Pilot Warning Instrument (PWI), and (3) Conspicuity Enhancement. A CAS will detect aircraft, evaluate the collision threat, and determine and indicate the escape maneuver to be executed by the human pilot or by the auto-pilot. Such systems must be compatible with maneuver capabilities of current and future vehicles. A PWI will alert the pilot to other aircraft in the same altitude segment and provide bearing, range, or other appropriate information to materially increase visual acquisition range. Conspicuity Enhancement includes high visibility paints, lights, and other devices to make aircraft easier to discern by the pilots' unaided eye. The PWI and conspicuity enhancement are complementary in nature - the PWI initiates concentrated "looking" and enhancement makes "seeing" easier. Visual systems are expected to be of almost no value for supersonic transports during cruise, except in overtaking situations, but could help in terminal areas.

The CAS system requirements are readily established (although the accomplishment of these requirements has proved to be extremely difficult). Basically, the equipment has only to inform the pilot of an appropriate escape maneuver. The implication is that there is no output from the equipment when not on a collision course, hence, no reason for distracting the pilot with unessential information. A second implication is that simply being on a collision course is not sufficient cause for an output from the system; one more situation must be met, namely, that the time remaining until the predicted collision is sufficiently short to warrant the execution of an avoidance maneuver. This last point minimizes the number of maneuvers required and provides for compatibility with existing and future Air Traffic Control Procedures; for under these conditions, the equipment output only occurs after the time when a controller would normally have vectored the aircraft involved. The CAS may serve as a backup to the primary means of maintaining traffic separation and in view of its airborne status, it can function in areas that are not serviced by ground facilities. In general, the principal design problems result from the accuracy, at maximum critical range, with which the several parameters must be measured or derived in a multi-aircraft environment and further development is required.

The PWI situation is quite different than that of the CAS for we do not know the value of presenting the pilot with the different kinds of information of varying accuracies. Said another way, we know the pilot needs help, however, we are uncertain how best to help him.

Conspicuity Enhancement experimenters have verified that visual acuity is greatly improved by alerting and positional queing; alerting alone is not sufficient. Test flights have shown that a precisely informed observer can detect intruding aircraft at ranges three to four times greater than actively searching pilots can.

There are at least two other problem areas closely related to collision avoidance schemes: altimetry accuracy and aircraft maneuverability. Recognizing the inherent collision hazard between high-speed aircraft using station-pressure altimeter settings, the FAA is investigating the effect of requiring standard pressure altimeter setting (29.92) upward from the base of the Continental Control Area (14,500 feet MSL). Standard pressure altimeter setting is presently required on over-water flight at all altitudes in oceanic control areas and Flight Information Regions and while flying at and above 24,500 feet MSL in the Continental Control Area. Also under study by the FAA is the concept of a rule requiring altimeter correction cards in each aircraft. Static pressure systems in individual aircraft vary sufficiently that the same altimeter setting could produce different readings. The end product that we are concerned with is a maneuver that will avoid an impending collision. This maneuver must be considered in several ways; for example, effectiveness in providing separation, aircraft structural limitations, passenger comfort, and compatibility with the traffic control system. Avoidance systems must, then, consider the maneuver capabilities of the aircraft.

## IX. Instrumentation

Many instrumentation problems for fixed wing aircraft are contingent on the operating speed and altitude of the airplane. It is generally agreed that the present instruments are satisfactory for aircraft which operate at speeds up to about 350 knots. For high subsonic speed aircraft operating up to altitudes of 42,000 feet, the present instrumentation is unsatisfactory and is imposing substantial performance penalties on turbojet powered aircraft. In addition to inadequate instrumentation, methods for rapid and accurate system calibration have also been lacking and this has magnified the problems.

Penalties for the use of the present instrumentation appear in many forms, some of which are (1) reduced payload due to excessive fuel reserves (fuel reserves for a modern jet transport may vary from 13,000 pounds to 28,000 pounds, while the payload varies from 20,000 to 36,000 pounds and it follows that a 1-percent increase in fuel reserves can decrease the payload as much as 1.4 percent), (2) precautionary landings (when the performance of the airplane, the fuel consumption and the fuel on board cannot be accurately determined it often becomes prudent to land at a point other than the intended destination which increases the operational costs) and (3) excess weight (when the fuel reserves or the total fuel loads are larger than necessary, the increased weight is reflected in increased drag).

The present type of pressure altimeter is rapidly becoming obsolete. Its function and limitation is that it measures pressure. For the altitudes of future manned vehicles some new system must be devised to supplement, if not replace, the pressure altimeter. Already there is a vast amount of airspace unusable due to the 2,000 feet of vertical separation required above 29,000 feet. This subject has previously been explored by the NASA but the problem still persists.

Temperature-indicating problems tend to fall into three speed categories: subsonic, supersonic, and hypersonic. At subsonic speeds current ram air temperature measuring equipment capable of withstanding the aircraft environment is too coarse for accurate thrust settings and also is unsuitable for determining small atmospheric temperature changes. In addition, the ram recovery factor does not appear to be either predictable or controllable. In order to take full advantage of jet streams, static air temperature measurements within $\pm 1^{\circ}$ C are necessary. Since current static air temperatures are computed from ram air temperature and Mach number, accuracies of $\pm 1^{\circ}$ C are not now possible. Some system for measuring static air temperature (i.e., the vortex thermometer) independently from the ram temperature would be beneficial to aircraft operations.

At supersonic speeds, ram and static air temperature measurement problems similar to those stated at subsonic speed exist and are made more complex because of heat radiation from the vehicle caused by the higher speeds.

At hypersonic speeds the problem of measuring ram and static air temperature still exist of course and with much more vehicle radiation. Also means must be found to measure and indicate leading-edge temperatures up to $3{,}000^{\circ}$ F. Engine combustion chamber temperatures up to $7{,}500^{\circ}$ F may exist in hypersonic vehicles and may need to be measured for control purposes. This measurement problem is expected in varying degrees in air-breathing engines, rockets, and ram jets. Fuel temperature measuring equipment capable of reasonable accuracy to $-425^{\circ}$ F will be needed for hydrogen fueled engines and an accurate fuel quantity indicator capable of operating at this temperature must also be developed. High temperature ($2{,}000^{\circ}$ F) transducers will be required for use with variable area inlets and nozzles on supersonic and hypersonic vehicles.

Inaccuracy of fuel quantity measurement is probably the most important single problem facing current and future aircraft because the fuel is such a large percentage of the gross weight. There is a great need for an improved method of measuring fuel quantity and flow rate. The problem is difficult because of (1) the rather wide range of fuel densities, from 5.8 to 7.1 pounds per gallon, (2) the odd fuel tank shapes, (3) the requirement for accuracy with the fuel tank pitched and rolled at least $\pm 5^{\circ}$, and (4) the wide range of operating environmental temperatures, pressures, vibrations, and decelerations.

The summation of the engine pressure ratio errors and the RPM errors make the current thrust measurement relatively inaccurate. With the addition of variable area nozzles and inlets on supersonic and hypersonic airplane types, new or improved methods of thrust measurements are needed.

Supersonic and hypersonic aircraft may be required to incorporate a fuel vapor inerting system in the fuel tanks due to expected high fuel temperatures. A problem will exist to provide for instrumentation useful to the flight crew in indicating when the inerting system is functioning properly.

As noted under I.- Vehicle Performance, an accurate measure of stall speed is required.

For hypersonic aircraft certainly, and for supersonic aircraft probably, there will be a requirement for angle-of-attack and angle-of-sideslip measurement with respect to the free stream in cruising flight. In hypersonic aircraft it is expected that these measurements will be fundamental performance parameters as temperature variations on the body or wing.

## X. Medical and Human Factors

In considering aircraft operating problems in relation to supersonic transport and altitudes to 100,000 feet it is important to plan via the team approach. Consideration of the human factor after the aircraft has been built is a luxury the industry cannot afford. The human factor and related medical problems must be solved before or simultaneously with other operating problems of the supersonic transport.

Military experience with subsonic aircraft was directly applicable to the commercial jet transport development. This is not true in the case of the supersonic transport trend to operations at altitudes approaching 100,000 feet. For example, military experience with pressure suits is not applicable to supersonic transport passengers. For this reason fail-safe concepts for supersonic transport cabins must be assured and research and development are necessary to determine the critical human functions which must be protected in supersonic operations.

### 1. Cabin Noise

The high level of boundary-layer noise at Mach 3.0 requires the development of new, more efficient sound attenuation techniques and/or materials in order to permit passengers to fly in a relatively quiet cabin. The present knowledge of noise and its effect on speech intelligibility, which is important to crew and passengers, appears sufficient to define cabin noise limits.

2. External Vision

The desirability of windows is a psychological as well as a structural problem and requires analysis. There may or may not be adverse passenger reaction to lack of windows. Passengers and crewmen in existing vehicles frequently travel for hours and days without external means of orientation. At very high altitudes there will be no means of external orientation and passengers might react favorably to well-planned illumination and decor which include murals or other means to which people are customarily oriented. However, there is evidence that the existence of windows will be a competitive sales item on one hand and on the other may not be permitted in order to maintain structural integrity.

3. Medical Qualification

Present medical screening of crews is probably satisfactory to establish the basic physical capability and basic health. The requirements for proper crew selection in supersonic flight is psychophysiologic in nature and deals with integrative and coordinated functions. The subject of medical examinations for passengers on supersonic aircraft has been previously raised but discarded as being very pessimistic.

4. Rates of Descent

There is a minimum safe absolute pressure to which we can transiently expose passengers and crew without pressure suits, considering the effects of absolute pressure reduction, rate of pressure change, temperature, and oxygen requirements on reversible morbidity (passengers) and functional capability (crew).

5. Passenger Indoctrination

The limited time of human consciousness in an emergency requires prompt action on the part of the passenger to follow definite emergency procedures.

6. Radiation

A summary state on radiation phenomena effects on crew and passengers of high altitude vehicles must be made and kept current. This statement should define in lay terms the known biological significance of radiation that will be encountered on the flights. Such a statement will help avoid unqualified speculation as to the hazards involved. Special attention should be given to the effects of solar protons and thin-down hits of high-energy radiation on human tissue.

7. Ozone

There appears to be sufficient information to indicate that as far as passengers and crew are concerned, detrimental effects of ozone can be adequately handled with cabin air filtration. The source of cabin pressure and the means of its generation are important. However, a maximum allowable concentration (0.1 ppm) is published for ozone. The problem requires engineering evaluation and solution and is not a biologic problem. However, instrumentation may be a problem. Rocket and balloon ascent tests cannot simulate the conditions within an aircraft cabin. Observations indicating a possibility of ozone concentrations 100 times the maximum allowable on compression of the ambient air have little meaning unless it is known what happens to the ozone during heating and pressurization.

## XI. Crashworthiness

### 1. General

Crashworthiness of aircraft implies structural capability beyond the normal operational requirement and provides that extra resistance to structural collapse for the purpose of reducing occupant incapacitation and personal injury to a minimum. In addition to determining the probable causes of an aircraft accident, investigative bodies should also determine the probable causes of injuries. The objective is to obtain design criteria to improve crashworthiness. Based on these precepts, impact survival of the occupants of relatively intact areas depends upon two factors:

(a) The occupant must participate in his environments deceleration and this requires an adequate restraint system comprised of seat, seat belt, and floor anchorage.

(b) The occupant must not be exposed to dangerous or fatal contact injuries and this can be achieved with a noninjurious contact environment.

The problem of air transport accidents involves not only survival of an accident with minimum injury but also rapid evacuation. It includes the study of structural collapse or deformation, and the energy absorption characteristics of the structure; tie-down of occupants and their physiological capacity to withstand forces; the elimination of loose or inadequately fastened objects that might become missiles; delethalization of the environment, the design of structure and fuselage contents so that they will not be likely to impede escape; the lighting (inside and outside) and communication systems; escape routes and means of egress; the prevention of fire or keeping fire at sufficient distance to provide opportunity to escape; (consideration should be given to the use of bladder-type fuel cells especially in helicopters); the design of latches, handles, seat belts, emergency exits so that they can be operated naturally in any position of the fuselage with a minimum of instruction; provision for protection of the elderly, infirm and infants as well as the normally active occupant; jam-proof doors and exits; means to open exits from the outside as well as from within; and provisions for escape after ditching.

## XII. Community Relations

The community acceptance of aircraft operation poses one of the most serious operating problems in air transportation. The problem up to the present has been one mainly of acceptance by communities in the neighborhood of busy airports. However, with increased population, urbanization, sonic boom frequency, and accidents the problem will become more acute.

The problems are induced by (a) the noise itself (speech and sleep interference) and noise considered by the community as a threat to safety from falling or intruding aircraft (b) accidents (especially mid-air collisions) independent of noise or annoyance (c) other nuisances introduced by aircraft as: ground operation of engines; air pollution; smoke; dust (from V/STOL aircraft); fire following crash in inhabitated areas; effects on animals; pressure wave effects on fragile structures; etc.